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ble in ordinary naval routine work, is not very well adapted to work of this character.

Much credit for the practical efficiency of the time service is due to the Hydrographic Office and its branch offices for co-operation in connection with time-balls and other methods of distributing the time amongst navigators, and to the Western Union Telegraph Company, which also itself utilizes the time by correcting electrically many hundreds of clocks daily, and which has been of great assistance in connection with telegraphic longitude determinations and occasional time-signals to surveying vessels far south along the coast of Lower California.

If the investigation explained in the accompanying paper adds to the efficiency of this service, and to that of other services engaged in similar work, the writer will feel well repaid for the study and effort devoted to it at intervals between pressing official duties during the past six months.

THE RISE AND PROGRESS OF ASTRONOMY IN CENTRAL EUROPE.

By Sidney D. Townley.

During a stay abroad in 1895 and 1896, the writer obtained photographs of many of the observatories of Germany. It was thought that a reproduction of some of these views, together with descriptions of the buildings and instruments and short historical accounts of these observatories, would be of interest to the students of astronomy. In preparing the material for publication the scope of the work, as often happens, has been enlarged gradually, until it has reached that indicated in the above title. The title should perhaps have been somewhat restricted — for it is my intention to treat mainly of the practical or observational side of astronomy, and to touch upon considerations of a theoretical nature only in so far as is necessary to bring out the development of the practical branch of the science.

Six names, Copernicus, Tycho Brahe, Kepler, Galileo, Gauss, and Bessel, stand out pre-eminently prominent. These are almost household words to the student of astronomy. Their lives and works are familiar to nearly every one. Some of them have been written and rewritten in the greatest of detail. It is not my purpose to go into the details, but a proper development of the subject in hand demands at least an outline of the works of these men.

The fall of Constantinople (1453) marks the beginning of modern astronomy. The sages who had gathered in the Grecian empire were scattered over Western Europe. To be sure, the Ptolemaic system was introduced into Spain some centuries before this. The Alphonsine tables were computed in the thirteenth century; but this was only a faint and solitary star in the firmament of the dark ages, and it was entirely lost in the dawn that slowly spread over Central and Western Europe in the fifteenth century. The Ptolemaic system of the universe had been accepted and taught for centuries, and it was not until the epoch-making work of COPERNICUS was put forth that the foundations of this mighty edifice of epicycles began to totter.

Although the work of COPERNICUS was the first great one in the progress of which we are dealing, still a beginning had already been made when COPERNICUS appeared, and it is perhaps well to note first these early attempts. One event leads to another, and it is seldom that even the work of a great genius stands alone. Previous events have created an atmosphere of unrest, indicated the necessity of change, perhaps even pointed out the way or laid a foundation for his work. The great man seems to come when the conditions are ripe for his coming.

The first astronomer of note of whom history tells us was GEORGE PURBACH, an Austrian (1423–1461). In a work, *Theoricæ Novæ Planetarum*, he attempted to revive the old method of material spheres. Learned men were then beginning to pay some attention to physical subjects, and PURBACH doubtless had difficulty in perceiving why, without any known cause, celestial bodies should describe in space circumferences of imaginary circles whose centers moved upon the circumferences of other circles equally imaginary. Vastly more important, however, was PURBACH'S other contribution to astronomy — the introduction into Europe of the methods of trigonometry, invented several centuries before by the Arabians. PTOLEMY'S methods were all geometric; and when we stop to think of how dependent practical astronomy is upon the methods of trigonometry we can scarcely overestimate the importance of PURBACH'S effort in this direction. This was the beginning of those transformations which finally led in the practical astronomy to the simple, elegant, and exact formulæ of the great BESSEL.

Among the pupils of PURBACH the most noted was JOHANN MUELLER (1436–1476), born in Königsberg, and generally known by the name of REGIOMONTANUS. He soon became a co-worker with PURBACH, and the two not only studied diligently the works of PTOLEMY, which had been the extent of astronomical study for centuries, but *began taking observations* in Vienna with some crude instruments, perhaps not even so accurate as those possessed by HIPPARCHUS. Crude as these instruments were, they were yet sufficient to show that the positions of the planets given by the Alphonsine tables differed widely from the true positions. After PURBACH'S death REGIOMONTANUS traveled in Italy, and while in Venice wrote a treatise on trigonometry and constructed a table of tangents. He did much to develop and extend the application of this useful branch of mathematics. In 1471, he returned to Germany, and settled in Nuremburg, at that time the chief center of German industry and literary life. Here, through the co-operation of a wealthy citizen, BERNARD WALTHER (1430–1504), the first European observatory was built, and observations begun about 1472. A comet was observed by them in that year. They originated several new methods of observing, and greatly improved the method of recording the time of an observation. The method of the ancients was very rough — simply morning, evening, or midnight. The Greeks used a clepsydra or a sun-dial, but it was not until the time of REGIOMONTANUS that a more accurate method was introduced. His method was to determine the time of observation by an altitude of the Sun or a star simultaneously taken, a method susceptible of great precision. WALTHER was the first to make use of clocks to measure short intervals of time. The clock consisted of wheel works to which motion was given by a weight, but it was not until the time of GALILEO that a pendulum was added to control the running of the clock. WALTHER was also the first to employ a more accurate method of observing the positions of the planets. In ancient times the longitude and latitude of a planet were observed with an astrolabe, the longitude being obtained when the Sun and Moon were visible at the same time. First, the difference in longitude between the Sun and Moon was measured, then the difference in longitude between the Moon and planet. The longitude of the

Sun was taken from the tables, then, by means of these two differences, the longitude of the planet was obtained. The latitude was measured directly with the astrolabe. Now, WALTHER, instead, measured the angular distance of the planet from two or more known stars, and then, by the methods of spherical trigonometry computed the latitude and longitude of the planet, a method in some respects similar to that now used to determine the position of a planet or comet with an equatorial telescope.

That, however, which added most to the fame of REGIOMONTANUS was the publication of his celebrated ephemerides, the first of those important adjuncts of practical astronomy. The ephemerides were soon made known to navigators, and it was by the aid of these that COLUMBUS first crossed the Atlantic Ocean. REGIOMONTANUS met an early death, but during the twenty-eight years that WALTHER survived him many observations were made at Nuremburg. These were published in 1544.

But one other name of note remains to be mentioned before coming to COPERNICUS. PETER APIANUS, who taught in the university at Ingolstadt, published in 1540 a large work, *Astronomium Cæsareum*, an attempt to further prolong the life of the Ptolemaic system. The book was highly received at the time. But APIANUS is perhaps more deserving of a place in history from the fact that he was the first to discover that the tail of a comet is always turned away from the Sun.

Thus, though the Ptolemaic system was still tenaciously clung to, yet considerable had been accomplished before COPERNICUS appeared on the scene. Trigonometry was introduced and developed, tables of sines and tangents constructed, ephemerides published, observations made, clocks used, and, above all, a spirit of investigation had arisen. The Ptolemaic system had become exceedingly cumbersome, and observations showed, after a lapse of fourteen hundred years, though epicycle upon epicycle had been added, that it represented the true motions of the planets very imperfectly. The time was ripe for a COPERNICUS. He came.

Born at Thorn, a town of the Hansa League, then under the sovereignty of Poland, NICOLAUS COPERNICUS (1473–1543) studied at Krakau and Bologna, taught and took orders in Rome, later returned to his native country, settled in Frauenburg, Prussia, and there spent most of his life. At Krakau he became a doctor of medicine, and did not study mathematics and astronomy seriously until he went to Bologna. At Rome, COPERNICUS was installed as professor of mathematics. Here he began to make astronomical observations. The fame of these and the clearness of his lectures soon gained for him a place among the most learned of astronomers. His observations were continued later at Frauenburg. These observations consisted in obtaining the longitudes and latitudes of the planets, the obliquity of the ecliptic, and the period of the Sun's return to the equinoxes. COPERNICUS, however, never entered seriously into the business of observing, and the results in this line were insignificant compared with those of TYCHO, brought forth a few years later.

At Frauenburg COPERNICUS led an uneventful life as a canon of the Church. Of his daily labors we know but little; still much of his time must have been given to matters astronomical, else he could never have given to the world that great work, *De Revolutionibus Orbium Cœlestium*, published in 1543, only a short time before his death. Of this work it is perhaps necessary to say but little. Its great principles are familiar to all students of astronomy. It is perhaps well to point out, however, that the system promulgated by COPERNICUS was in some ways essentially different from that which now bears his name. COPERNICUS brought forth only a portion of the truth. He substituted diurnal motion of the Earth for the diurnal motion of the heavens, and a heliocentric motion of the planets and the Earth for a geocentric motion of the planets and the Sun. These were two great principles, and in that much the present system is rightly called Copernican. This, however, was only a beginning, and it was not until TYCHO, KEPLER, GALILEO, and NEWTON had lived and worked that the true nature of planetary movements became known. COPERNICUS still held to the idea of circular motion; so, in order to explain the irregular apparent motions of the planets and the variation in the apparent diameter of the Sun and Moon, he was obliged to retain some of the epicycles of the Ptolemaic system.

Even though COPERNICUS discovered only a portion of the truth, still his researches marked a great advance, and when we think of the condition of learning, and especially of science at the time he lived, we cannot have other than profound admiration for the man possessed of an intellect to work out these theories, and the boldness to present them to the world. The world had only begun to awaken from the long sleep. Aristotelian philosophy was still firmly intrenched in all citadels of learning, the Ptolemaic system of the universe had reigned undisputed for fourteen hundred years, the Scriptures were everywhere interpreted literally; the Sun, Moon, and stars were made for the glory of the Earth, and to dispute this and consider the Earth as but one of many, as COPERNICUS did, was little short of heresy. Perhaps it is fortunate that COPERNICUS did not long survive the publication of his work. COPERNICUS had taught his system quietly for many years, but it was not until long after his death, that it came under the censure of the Church. Perhaps the facts that COPERNICUS himself was a churchman, that the cost of his book was defrayed by a cardinal of the Church, and that the book itself was dedicated to the Pope, acted to disarm suspicion. COPERNICUS was certainly shrewd, perhaps unwittingly so.

Many years elapsed before the theory of COPERNICUS was generally accepted and the Ptolemaic system finally abandoned. This is not to be wondered at, when we consider that there was then no proof that the Earth moved. That came much later, when the flattening of the Earth was found, aberration discovered, and the memorable experiments of GALILEO and FOUCAULT performed. In fact, about the only thing that recommended the Copernican theory was its simplicity. The Ptolemaic theory had much in its favor. It had been accepted as true for hundreds of years; our sense of sight tells us that the heavens move above us and not the Earth beneath us; it agreed with the teachings of the Church. And when we consider the great weight then given to things ancient and the great power of the Church, the wonder perhaps is that the Copernican theory found as many followers as it did.

The theory of the Earth's motion was not original with COPERNICUS, for it was advanced many hundred years before by a Greek philosopher. Why was the theory accepted in the sixteenth century and rejected in ancient Greece? No doubt, one great factor was the earnestness and power with which COPERNICUS taught this theory to his pupils. Yet, on the other hand, there were conditions which favored COPERNICUS; the newly invented art of printing preserved and propagated his ideas; he lived at a time when the spirit of change, revival, and reformation was abroad; he lived at a time when the Ptolemaic system had been tried sufficiently long to be found cumbersome and unsatisfactory.

Although the work of COPERNICUS led to great results, yet his methods were not scientific. Astronomy, indeed, had hardly yet become a science. It might, perhaps, have been rightly called mathematical speculation. The deductive method of mathematics was used. Axioms were assumed, and the consequences deduced by processes of reasoning. It had not yet been perceived that the true method of scientific research is an inductive one. Observations must first be made and facts ascertained. The theory must be in accord with the facts. If this is not the case, then the theory is certainly false. If the theory does satisfy the facts, then it may be true. We shall see in the next paper how the great Danish astronomer was the first to perceive and carry out true and accurate methods of scientific research.

In criticising and pointing out defects in the work of COPERNICUS, I do not wish the reader to think that I underestimate his work. The defects belonged more to the age than to the man. His work was profound, it was epoch-making; still he was not by any means a genius; things did not come to him by inspiration. He was a quiet, deep, incessant thinker, earnest in his belief and fearless in its expression. History has always given, and I think always will give, COPERNICUS a place among the great men of the world.

(To be continued.)

A CLUSTER OF METEORS.

By SIDNEY D. TOWNLEY.

On Friday evening, 1899, April 7th, at about 8:45 o'clock P. S. T., a very peculiar appearance of meteors was observed at the Students' Observatory of the University of California. While I was looking at the constellation of *Orion*, a whole "flock" of very faint meteors appeared at the same instant, some six degrees to the southeast of *α Orionis*, about in the head of the Unicorn. They were moving northwest, slowly, about parallel to the horizon, and remained visible not more than a second. The "flock" was about one and a half degrees wide, and the path two or three degrees in length. None of the meteors were brighter than a fifth-magnitude star. It was impossible to make an accurate